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TEMPORARY FIXING SYSTEMS FOR APPLICATIONS IN MICROROBOTICS.

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Abstract: This paper focuses on temporary fixing systems for microrobotics. Several solutions from the state of the art are presented and compared: solutions based on mechanical bending, electromagnetic elements, electrostatic forces, glues, polymers or Van der Waals forces. From this analysis, we designed and developed a new system based on thermal glue (that permits to exchange the tip part of a microgripper) for microassembly stations. This system brings a high flexibility and compactness for microrobotic applications.

Keywords: Micromechatronics, temporary fixing systems, microrobotics, micro-assembly, tool changer.

1. INTRODUCTION

In our everyday life, we are using more and more miniaturized products. Lot of microcomponents are nowadays produced by parallel microfabrication processes. Nevertheless, these products are also becoming more and more complex and propose a growing number of functions. As a consequence, more and more hybrid microsystems using several incompatible processes requiring assembly tasks are developed. Assembly can be performed by self-assembly or by serial assembly (robotic assembly). In this aim, since about one decade, research fields concerning micromanipulation and micro-assembly have been widely developing to propose robotic systems able to manipulate particles and assemble microcomponents. Thus, micromechanisms (as micromotors (Klocke & Kleindiek Nanotechnologie n.d.), microgears (IMM n.d.)), miniature components (mass spectrometer (Udeshi and Tsui 2005), capsule endoscope (Norika n.d.)) and hybrid and/or 3D MEMS and MOEMS can be fabricated (Lehto and Marttiin 2005)(Weck and Peschke 2003).

Robots used to assemble microcomponents must be compact either because of the high precision required (related to the stiffness of the structure) or due to the size of their surroundings. Moreover, these system are mainly used in confined spaces for:

- assembly tasks in a microfactory (Rakotondrabe *et al.* 2004),
- manipulation tasks in the chamber of a SEM (Scanning Electron Microscope) (Mazerolle *et al.* 2004).

One also has to notice that robotic assembly mainly aimed at flexible assembly (Chollet *et al.* 2003).

To perform assembly processes in confined spaces with flexibility, temporary fixing systems like tool exchange systems must be developed. It is also usefull to develop systems like microvices to enable the temporary fixation of objects or of a partially assembled components during the assembly process. Nevertheless only a few temporary fixing

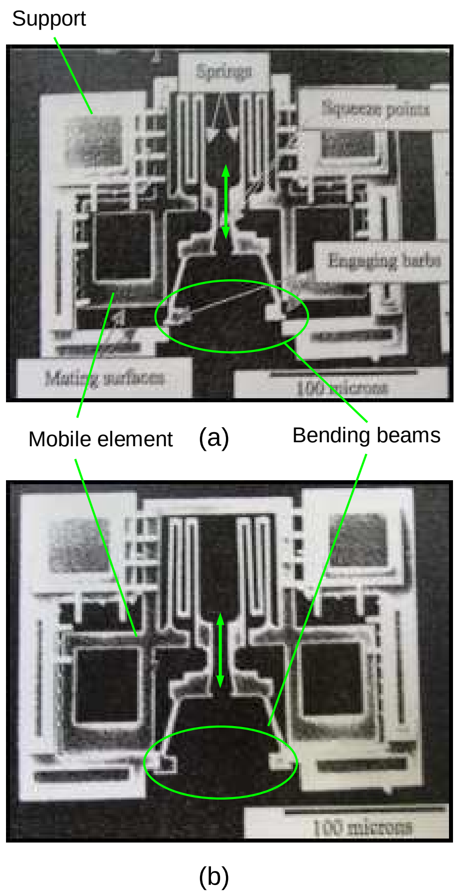

Fig. 1. Micromechanical connector: (a) the mobile part is free - (b) both parts of the connector are fixed together. The arrow corresponds to the direction of motion of the mobile part (from (Skidmore *et al.* 2000)).

systems have already been presented in the state of the art.

This paper will focus on several solutions suitable to microrobotic applications. Solutions based on mechanical bending, using electromagnetic components, electrostatic forces, polymers, glues and Van der Waals forces will be presented in section 2. Section 3 will focus on the study and development of a new temporary fixing system used to exchange automatically the end-effectors of a microgripper.

2. TEMPORARY FIXING SOLUTIONS

2.1 Solutions based on mechanical bending

Temporary fixing systems based on a mechanical principle are widespread in machining and robotics at the macro scale. Until now, several research teams have worked to develop a system able to connect mechanically two micro-objects. Moreover, the constitutive parts of such mechanisms can be made with a high precision using microfabrication processes. As shown by Figure 1, connectors of some hundreds of microns in size have been developed, they are based on the bending of two beams (Tsui *et al.* 2004)(Dechev *et al.* 2003). These systems are quite efficient to fix two parts together, unfortunately, they are not reversible. Figure 2 displays an example of a microvice that is reversible but that is manually actuated. Such solutions suffer from material wearing that can decrease the performances of the system (positioning accuracy, force transmitted, automation).

At this time, none of these systems can be used to fix two parts in a reversible and automatic way, but, they show the potentiality of solutions based on mechanical bending.

2.2 Electromagnetic solutions

Physics laws prove that magnetic effects are favoured by scale decrease (Cugat 2002). Indeed, the reduction of the size of a magnetic dipole by a coefficient of 1000 causes a reduction by 100 of the magnetic force. So, the reduction of all the dimensions of the dipole by a factor of 10 creates an increase of the weight force ratio by the same factor. Thus, the use of magnets to develop a temporary fixing system is quite interesting.

In the same way, scale decrease does not appear in favour of the interaction between two microcoils as a first step. However, current densities are usually limited by overheating. As scaling down increases surface/volume ratio, thermal conduction and convection are easier (Peirs 2001). As a consequence, thermal problems are reduced by scaling the size of the components down. For these reasons current densities can be increased. For example, they are usually limited in copper wires to about 5 A/mm^2 whereas several thousands of A/mm^2 can be applied in microsystems. Finally, microcoils are also well adapted to make a temporary fixing system.

Scale effects are then in favour of electromagnetic elements. Blocking forces are also important but sometimes their effect at a distance can be damaging. For example, it can cause the magnetization or displacements of the manipulated object notably if this one is made of a magnetic material. Finally, this kind of solution is interesting but has to be developed cautiously.

2.3 Electrostatic solutions

Scale reduction is favorable for electrostatic forces mainly because their intensity decrease less than gravity force. Moreover, microfabrication processes are very well adapted to make stacks of conductive and insulating layers (Cugat 2002). Two

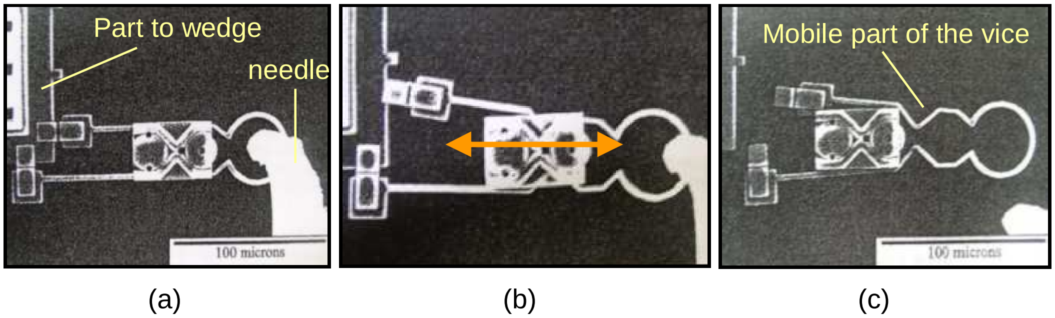

Fig. 2. Elements of a microvice system (from (Skidmore et al. 2000)). The mobile part enable to tight an object against a fixed support. (a) the object is fixed by the vice (b) the mobile part of the vice is translated to the right using a needle. The double arrow indicates the direction of motions of the mobile part of the vice (c) the object is free. Sequences a-b-c can be inverted to proceed to the fixation of the object.

parts can be temporary fixed by electrostatic attraction (capacitance effect). Supplying a voltage between both electrodes generate a force. Such a system can be developed quite easily, nevertheless high voltages are necessary that can be damaging like inside a SEM.

2.4 Solutions based on polymers and glues

Several kinds of glues or polymers enable the temporary fixing of two parts together. For instance, we can consider the scotch® (double-faced), post-it®, gel-pack® (currently used to hold small samples in their packaging) or PDMS (PolyDiMethlySiloxane). Such solutions can easily be developed, nevertheless they have two main disadvantages:

- the intensity of blocking forces between both assembled parts varies a lot with the number of experiments, in the range of several hundreds of per cent,
- dust used to be fixed on the working surfaces of the system, rapidly deteriorating its performances.

These remarks are confirmed by a research team that developed the mobile robot presented in Figure 3. Thus, even if such solution seems to be interesting, their reliability is weak even if a controlled environment can be used.

Thermal glues can also be used. They are solid at room temperature and have got a low melting point. Numerous of cycles of solidification-liquefaction can be performed by heating or cooling. Such glues have got a good fluidity when they are liquid, so, it can fit the roughness of both surfaces in regards. This solution has a lot of advantages but all the parts of the system must withstand liquefaction temperatures. Nevertheless, some of these glues have a low melting point (60 $^\circ$C).

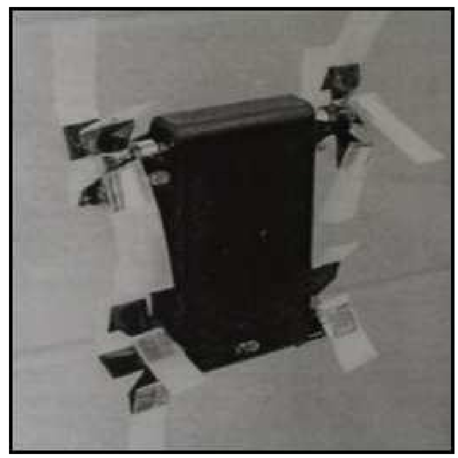

Fig. 3. Mobile robot with four wheels, each of them being equipped with four pieces of adhesive. This robot can move along vertical walls (from (Daltorio et al. 2005)).

2.5 Solutions based on Van der Waals forces

Van der Waals forces result from the molecular interaction between electric dipoles. Their intensity increases when the distance between two surfaces decreases. Theoretically, it is so possible to fix two parts together with a perfect plane to plane contact. Nevertheless the range of these force is about hundred nanometers making such solutions difficult to fabricate (Rougeot et al. 2005). To solve this problem, it is possible to develop a system fitting the roughness of a surface. This principle is the one used by the Gecko-Tokay lizard to move on every kind of surface even vertical or ceilings.

Indeed the foot of Geckoes are composed of flexible hair equipped with numerous spatulaes at their tip (figure 4). Their size help to fit the surface in regard. Van der Waals forces are maximum when they are parallel to the hung surface. Measurements shown that each spatula can support a force of 100 nN. As each feet of the Gecko is composed of billions of spatulas, the animal can

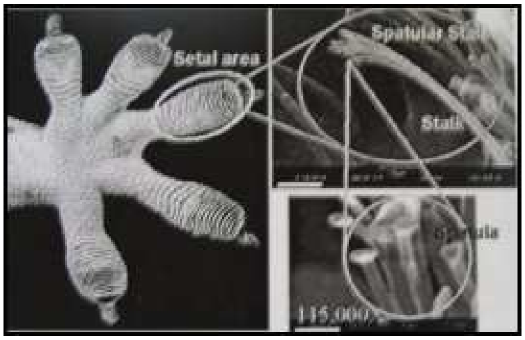

Fig. 4. Foot of Geckoes are composed of hair having spatulaes at their tip (100 to 200 nm in diameter) (from (Sitti and Fearing 2003)).

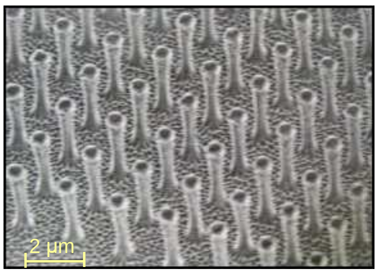

Fig. 5. Foot of Geckoes are composed of hair having spatulas at their tip (100 to 200 nm in diameter) (from (Geim et al. 2003)).

lift up to 40 kg that is to say 400 times its own weight (Autumn et al. 2000).

Several research teams currently work on the development of biomimetic materials based on this principle (see Figure 5). Geim et al. exhibit results where each hair enables a force of 70 nN which is close to the one for Geckoes. 1 cm^2 of synthetic hair can support 3 N. Nevertheless these structures are fragile and have a short lifetime due to the presence of impurities in air. Actually, lizards have a self-cleaning system but whose principle is still unknown by scientists.

2.6 Comparison of temporary fixing solutions

These temporary fixing solutions have different interests for microrobotics depending on their application. Indeed, their characteristics are greatly different in terms of reliability, force to transmit, reservibility, automation ability, SEM compatibility, perturbations due to the environment and perturbation caused on the manipulated objects. Figure 6 compares the different technical solutions of temporary fixing depending on these criteria. Let us note that several solutions can also be combined to perform a more efficient (but more complex) system.

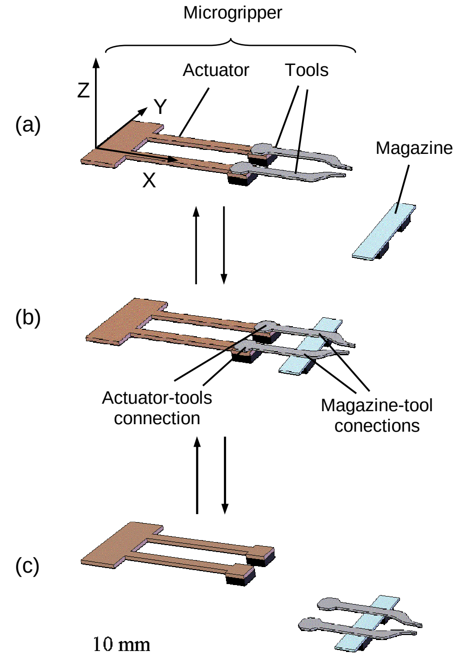

Fig. 7. Phases of tool exchange. (a) the pair of tools is fixed at the tip of the actuator of the migrogripper (manipulation configuration) (b) intermediate step (c) the tools are fixed on the magazine (tools exchange configuration).

3. APPLICATION: TOOL CHANGER FOR A MICROGRIPPER

Microassembly being one of the main research field of our laboratory, we are interested in developing temporary fixing systems like an automatic tool changer for a microgripper. The goal of this system is to use sequentially several kinds of pair of tools, each of them being dedicated to the manipulation of one family of objects. This system enables to fix alternatively a pair of tools either at the tip of the actuator of the microgripper or in a tools magazine as depicted in Figure 7.

3.1 Principe of the tool changer

To fix temporary a pair of tools at the tip of the actuator or in a tools magazine, a thermal glue is used. Small amounts of this glue are placed between the tips of the actuator and the tools (at the actuator-tools connections) and between tools and magazine at the tools-magazine connections. This glue is solid at room temperature and liquid at 65 $^\circ$C. To generate a phase change of this glue, surface mounted resistors are placed under each of the connections (actuator-tools connections and tools-magazine connections). These resistors are depicted as black elements in figure 7. A thermal study of this system has been performed to determine precisely the control of the different resistors

Solution	Mechanical bending	electromagnetic	electrostatic	glues	Van der Waals
Reliability	-	+++	+	+++	+
Force	+++	+++	+	+++	+
Resersibility	+	+++	+++	+++	-
Automation	+	+	+	+	-
SEM compatibility	+++	-	-	+	+++
Influence at a distance on manipulated objects	+++	-	-	+	+++

Fig. 6. Comparison of solutions for temporary fixing micro-objects.

of the system during a tool exchange cycle (Clévy et al. 2006a). Figure 8 depicts the sequences that has to be performed to process to a tool exchange.

3.2 Characterization of the system

The characteristics of the tool exchange system have been determined through measurements and are detailed in (Clévy et al. 2005). This system enables to perform automatically hundreds of cycles of tool exchange.

Mechanically, the glue film enables to transmit forces during micromanipulation tasks without any relative motion:

- the blocking force can get to 50 mN (Y direction, see figure 7),
- the insertion force can get to 10 mN (Z direction, see figure 7).

Otherwise, the peeling characteristics of a connection assembled using a thermal glue enables to remove both parts with a force of 25 mN. In the case of the tool changer, this permit to prevent from breaking the actuator of the microgripper that is fragile (made of piezoelectric PZT ceramic) for insertion operations.

The tool positioning accuracy is of 1 μm in average (and 3 μm at the most) for each direction between two consecutive tools exchanges.

Finally, the SEM compatibility of this system has been established and successfully experimented (Clévy et al. 2006b). This specific environment is very restrictive due to its environment (vacuum), the small free space and high electric fields.

4. CONCLUSION

Few temporary fixing systems adapted to microrobotics specificities have already been presented. Nevertheless, they are necessary to hold objects during serial assembly processes of microcomponents or, to design systems like tool changers. In this aim, several solutions of temporary fixing suitable for microrobotics are presented. These solutions are based on mechanical bending, electromagnetic elements, electrostatic forces, glues, polymers or on Van der Waals forces. The comparison between these solutions leads to the choice of the suitable one depending on criteria defining the developed system. A solution based on a thermal glue has been chosen to study and design a new automatic system for the tool change for a microgripper. This system bring a high flexibility and compactness notably in the aim of micro-assembly in a microfactory or of micromanipulation in the chamber of a scanning electron microscope. Finally, solutions based on thermal glues are well adapted to the specificities of microrobotics.

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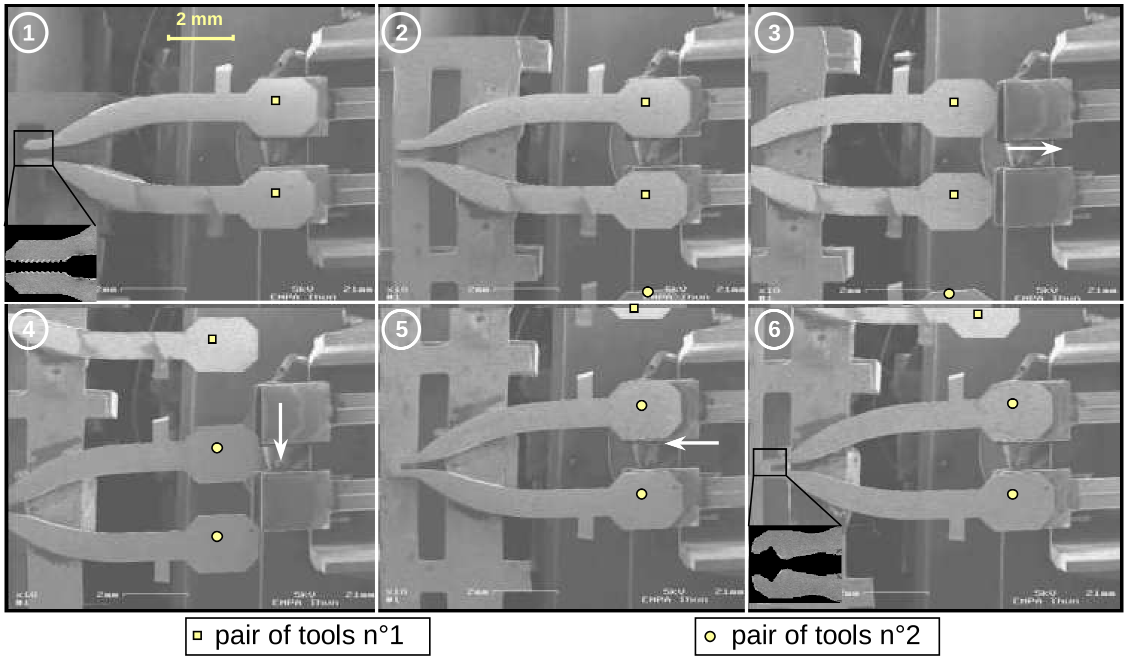

Fig. 8. Successive steps for exchanging a pair of tools in the SEM: (1) a pair of tools is fixed at the tip of the actuator - (2) the first pair of tools is fixed both at the tip of the actuator and on the magazine - (3) the first pair of tools is released in the magazine - (4) the actuator alone reaches the position of the second pair of tools - (5) the second pair of tools is fixed both at the tip of the actuator and on the magazine - (6) taking the second pair of tools of the magazine. The second pair of tools is fixed at the tip of the actuator.

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